STRATIGRAPHY AND CORRELATION OF TRIASSIC STRATA AROUND THE NACIMIENTO AND JEMEZ UPLIFTS, NORTHERN NEW MEXICO

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Abstract—Triassic strata exposed along the flanks of the Nacimiento and Jemez uplifts (Sandoval County, northern New Mexico) belong to the Middle Triassic Moenkopi Formation (Anton Chico Member) and the Upper Triassic Chinle Group (Agua Zarca, Salitral, Poleo, and Petrified Forest Formations). The Moenkopi Formation (strata previously assigned by most workers to the Permian Bernal Formation) is as much as 39 m thick and mostly grayish red sandstone, siltstone, mudstone, and intraformational conglomerate. It disconformably overlies the Permian Glorieta Sandstone and is disconformably overlain by the Agua Zarca Formation. The Agua Zarca is as much as 61 m thick and mostly white to brown, trough-crossbedded, quartzose sandstone and siliceous conglomerate. The overlying Salitral Formation is as much as 102 m thick and mostly purplish, smectitic mudstone. The Poleo Formation disconformably overlies the Salitral and is as much as 41 m thick and mostly grayish yellow, trough-crossbedded litharenite, subarkose and intrabasinal and siliceous conglomerate. Above the Poleo, the Petrified Forest Formation is as much as 340 m thick and dominated by reddish brown, smectitic mudstone. South of San Miguel Canyon (T19, R1W), the Poleo Formation essentially pinches out, though thin (<20m), lenticular equivalents of the Poleo are locally present as far southeast as Vallecito Creek (T16N, R2E). Furthermore, throughout Sandoval County, the lower portion of the mudstone-dominated interval above the Agua Zarca Formation, even where the Poleo Formation is absent, is dominated by purplish mudstone characteristic of the Salitral Formation. Therefore, to the south of San Miguel Canyon the Salitral and Poleo Formations can be recognized locally, but the thick, mudstone-dominated section above the Agua Zarca is assigned to the Petrified Forest Formation. The Correo Sandstone Bed crops out as a bench-forming sandstone up to 15 m thick at the top of the Petrified Forest Formation along the southern flank of the Nacimiento uplift. Fossil vertebrates indicate the Petrified Forest Formation ranges in age from Adamanian to Revueltian (latest Carnian-Norian) and support lithostratigraphic correlation of the Triassic strata exposed in Sandoval County to nearby Triassic outcrops in the Chama basin, Lucero uplift, and Hagan basin.

INTRODUCTION

Triassic strata exposed along the western flank of the Nacimiento uplift and around the southern edge of the Jemez uplift in northern New Mexico (Fig. 1) represent two tectonosequences. The lower tectonosequence is a relatively thin (up to 39 m) package of red-bed sandstones assigned to the Middle Triassic Anton Chico Member of the Moenkopi Formation. It disconformably overlies Middle Permian (Guadalupian) strata of the Glorieta Sandstone. The upper tectonosequence disconformably overlies the Moenkopi Formation or older, Permian strata, and is assigned to the Chinle Group. Chinle Group strata around the Nacimiento and Jemez uplifts are a thick (up to 400 m) sequence of red-bed mudstones with a relatively thick (up to 61 m) basal unit of sandstone and extrabasinal conglomerate. In this article, we review the stratigraphy and correlation of the two Triassic tectonosequences exposed along the flanks of the Nacimiento and Jemez uplifts. NMMNH refers to the New Mexico Museum of Natural History and Science, Albuquerque.

PREVIOUS STUDIES

Marcou (1858), in his geologic map of New Mexico, identified the red beds around the southern flank of the Jemez uplift as "New Red Sandstone," suggesting he considered them to encompass both Permian and Triassic strata (see Kelley and Northrop, 1975, fig. 8). Darton (1928) summarized what few observations had been made on these strata since Marcou had guessed their correct general age, and envisioned a two-part Triassic stratigraphic section around the Nacimiento and Jemez uplifts (Fig. 2). He applied Huene's (1911) term Poleo Sandstone, introduced in the Chama basin to the north, to the lower, sandstone-dominated part (about 200 ft thick according to Darton) of the section. He tentatively assigned the upper, mudstone-dominated part (400 to 600 ft thick according to Darton) of the section to the"Chinle(?) Formation." Red beds below the "Poleo" were assigned by Darton (1928) to the Permian "Chupadera Formation."

Renick (1931), in his study of the ground-water resources of western Sandoval County, used much the same nomenclature of the Triassic section as Darton (1928). He did introduce a new name, the Señorito Sandstone Lentil, for a 92-ft-thick unit of sandstone and conglomerate at the base of the Triassic section at Señorito Canyon (T20N, R1W) (Fig. 2).

Wood and Northrop (1946) mapped the geology around the flanks of

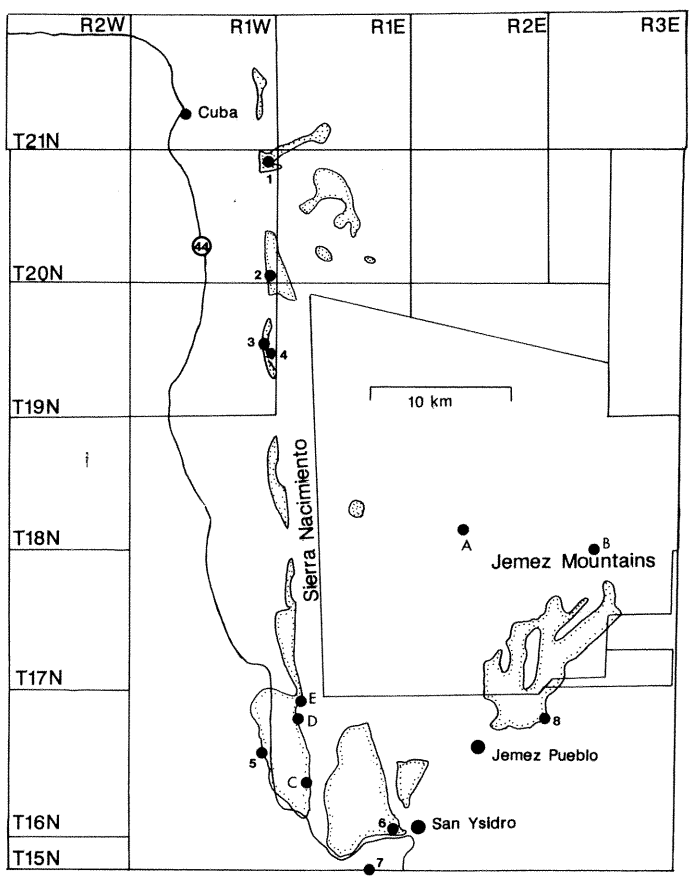

FIGURE 1. Distribution of Triassic outcrops and measured stratigraphic sections (letters and numbers correspond to those in Figures 3 and 5) around the Nacimiento and Jemez uplifts. Geology after Dane and Bachman (1965).

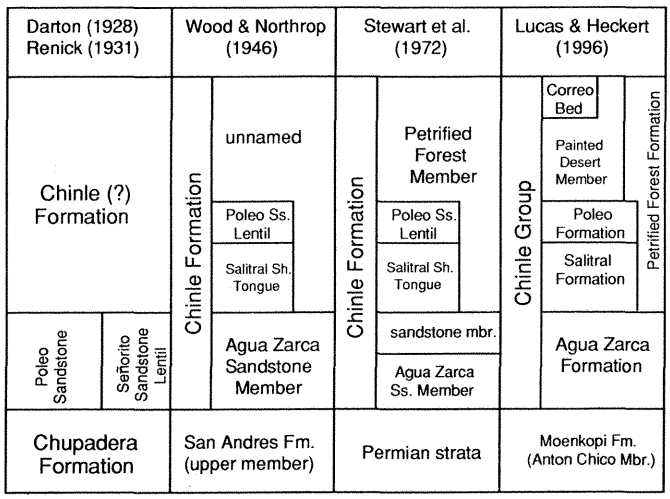

FIGURE 2. Evolution of stratigraphic nomenclature of Triassic rocks exposed around the Nacimiento and Jemez uplifts.

the Nacimiento and Jemez uplifts, and established most of the nomenclature of Triassic strata still used in this area. Above the "upper member" of the San Andres Formation (later named Bernal Formation by Bachman, 1953), Wood and Northrop (1946) assigned the Triassic strata to the Chinle Formation consisting of four members (ascending): Agua Zarca Sandstone Member, Salitral Shale Tongue, Poleo Sandstone Lentil (a modification of Huene's [1911] term) and an unnamed, upper member (Fig. 2). Wood and Northrop (1946; also see Wengerd, 1950) recognized that Renick's (1931) Señorito Sandstone Lentil is the same as their Agua Zarca Sandstone Member. Particularly significant was Wood and Northrop's (1946) recognition that along the west flank of the Nacimiento uplift, the Poleo pinches out in the vicinity of San Miguel Canyon (T19N, R1W), so that to the south the Chinle above the Agua Zarca is thick succession of mostly red-bed mudstones.

Although Wood and Northrop (1946) introduced the stratigraphic terms Agua Zarca and Salitral in a legend to a map and failed to describe or designate type sections for these units, the U.S. Geological Survey recognized these names as official terminology (Keroher et al., 1966). Furthermore, although Renick's (1931) term Señorito had priority, the survey abandoned it and used Wood and Northrop's (1946) term Agua Zarca instead.

Momper (1957; also see Momper and Tyrrell, 1957) reassigned these basal Chinle units to the Moenkopi Formation, a miscorrelation that was not accepted by subsequent workers. Stewart et al. (1972) employed the stratigraphic nomenclature of Wood and Northrop (1946) with one modification. They (p. 206-207) identified an informal "sandstone member" for some Chinle strata near San Ysidro. Minor lithologic differences and different crossbed dip directions distinguished this unit from the Agua Zarca according to Stewart et al. (1972).

Beginning in the late 1960s, Woodward supervised a series of masters theses at the University of New Mexico that encompassed detailed mapping around the flanks of the Nacimiento and Jemez uplifts (Anderson, 1970; Kaufman, 1971; Schumacher, 1972; Ruetschilling, 1973; DuChene, 1973; Martinez, 1974; Timmer, 1976) that led to the publication of geologic maps (Woodward et al., 1973a,b, 1974a,b, 1977; Woodward and Schumacher, 1973; Woodward and Martinez, 1974; Woodward and Ruetschilling, 1976; Woodward and Timmer, 1979) that detailed the Triassic stratigraphy. Woodward (1987) provided an extensive synopsis of this work. Woodward (1987) and his collaborators essentially employed the stratigraphic nomenclature of Wood and Northrop (1946) (Fig. 2). They repudiated Stewart et al.'s (1972) "sandstone member" as based on "minor differences in lithologies and possible differences in source area" not worthy of separate stratigraphic designation (also see Lucas and Hunt, 1992).

Kurtz (1978; also see Kurtz and Anderson, 1980) studied the sedimentology of the Triassic strata exposed around the Nacimiento and Jemez uplifts. He essentially employed the stratigraphic nomenclature of Wood and Northrop (1946), except the informal (never published) term Red Mesa Sandstone Member was applied to the unit Stewart et al. (1972) termed the "sandstone member".

Hunt et al. (1988) and Hunt and Lucas (1990) reported the first age-diagnostic vertebrate fossils from the Triassic strata exposed around the Nacimiento and Jemez uplifts. Lucas and Hayden (1989, 1991) reassigned strata in this area identified as Permian Bernal Formation to the Middle Triassic Moenkopi Formation. Lucas (1991, 1993, 1995) and Lucas and Hunt (1992, 1993) reviewed the Triassic stratigraphy of Sandoval County and developed the stratigraphic nomenclature employed here (Fig. 2).

STRATIGRAPHY

Moenkopi Formation

The oldest Triassic strata exposed around the Nacimiento and Jemez uplifts belong to the Anton Chico Member of the Moenkopi Formation (Lucas and Hunt, 1987). These strata were previously identified as Permian and generally assigned to the Bernal Formation. However, lithology and regional stratigraphic relationships indicate these red beds belong to the Moenkopi Formation (Lucas and Hayden, 1989, 1991).

Moenkopi strata in this area disconformably overlie grayish orange to very pale orange, supermature, trough-crossbedded quartzarenite of the Permian Glorieta Sandstone (Figs. 3, 4A). A profound erosional disconformity marks the top of the Moenkopi Formation where it is overlain by the Upper Triassic Agua Zarca Formation of the Chinle Group. Typically, the basal unit of the Agua Zarca above the disconformity is a sili-

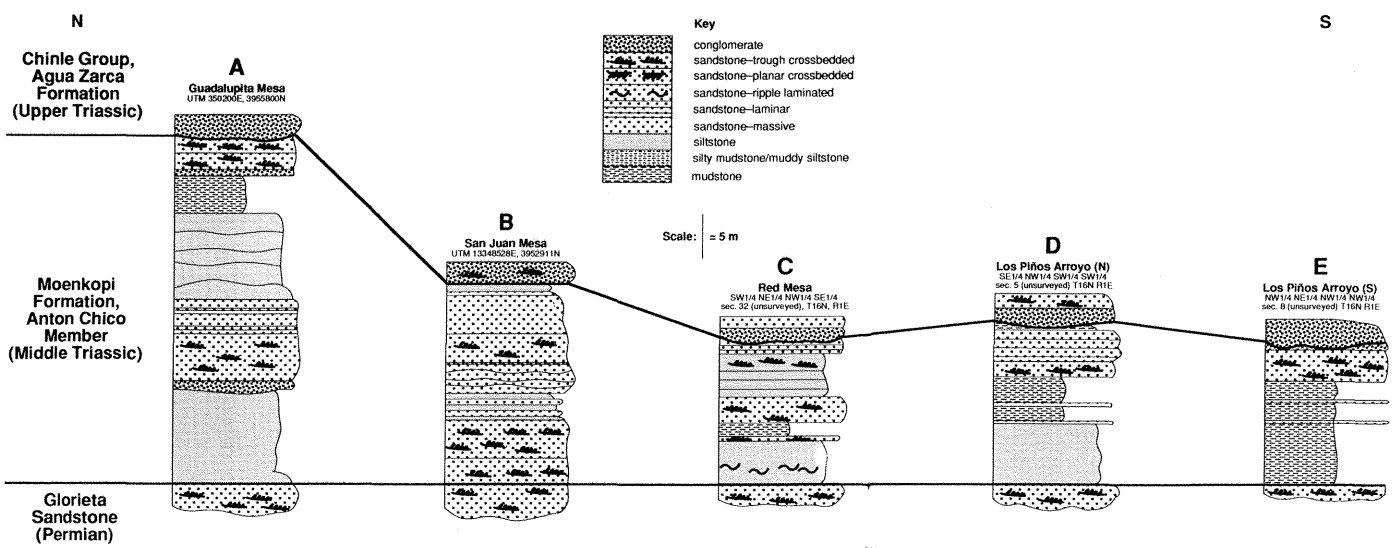

FIGURE 3. Measured stratigraphic sections of the Moenkopi Formation in Sandoval County. See Figure 1 for location of sections.

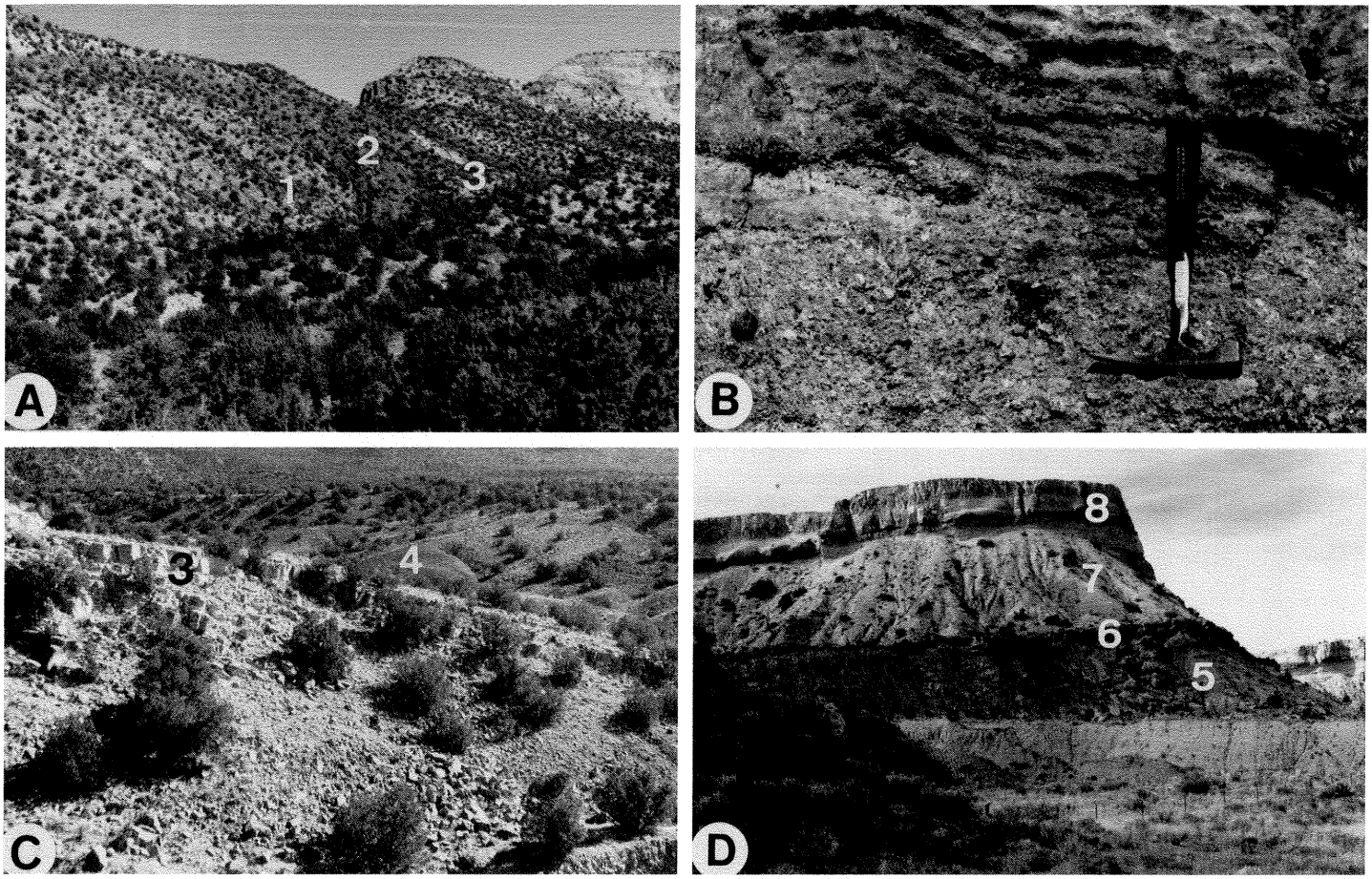

FIGURE 4. Selected Triassic outcrops around the Nacimiento and Jemez uplifts. A, Overview of Moenkopi (1) and Agua Zarca (2) Formation outcrops at San Juan Mesa (Fig. 3, Section B). B, Siliceous conglomerate of Agua Zarca Formation at San Juan Mesa (Fig. 3, Section B). C, Agua Zarca (3) and Salitral (4) Formation outcrops at Vallecito Creek (Fig. 5, Section 8). D, Outcrops of Petrified Forest Formation (5), including Correo Sandstone Bed (6), overlain by Jurassic Entrada (7) and Todilto (8) Formations just north of Cuchilla Arroyo section (Fig. 5, section 5).

ceous conglomerate that is poorly crossbedded, clast-supported and composed of quartzite, chert, siltstone, and fossil-wood clasts in a pale orange to pale brown matrix of fine- to very coarse-grained quartzose sandstone (Fig. 4B).

We measured five sections of the Moenkopi formation in the study area (Fig. 3). In these sections, the Moenkopi has a maximum thickness of 39 m on Guadalupita Mesa. Most of the Moenkopi Formation is siltstone and sandstone, with subordinate amounts of mudstone and conglomerate. Most strata are grayish red, but some mudstones are grayish orange. Moenkopi sandstones are mostly fine- to medium-grained, angular to subrounded wackes. Conglomerates are intraformational, composed of clasts of mudstone, siltstone and calcrete pebbles in a matrix of sandy siltstone. Sandstones and some siltstones display low angle trough crossbeds (paleocurrent azimuths are to the north or northwest) or laminar bedding. Siltstones and mudstones are generally sandy and calcareous. Lateral accretion surfaces, scour-and-fill, medium to coarse grain sizes and other features indicate a fluvial environment of deposition for Moenkopi strata in the study area.

The Moenkopi Formation is present throughout the study area as far north as San Miguel Canyon (T19N, R1W), where it is about 10 m thick. North of that point, the Agua Zarca Formation rests directly on Permian strata of the Glorieta or Yeso Formations (Woodward, 1987; Lucas and Hunt, 1992).

Chinle Group

Agua Zarca Formation

The basal unit of the Chinle Group throughout the study area is the Agua Zarca Formation, as much as 61 m of sandstone and conglomerate (Fig. 5). This well-indurated, resistant unit forms cuestas and caps benches and escarpments wherever the base of the Chinle Group is exposed around the Nacimiento and Jemez uplifts.

Sandstones of the Agua Zarca Formation are white to brown, medium- to coarse-grained quartzarenites that are typically crossbedded (Fig. 4C). Conglomerates (Fig. 4B) are typically siliceous; dominant clasts are gray metaquartzite pebbles up to 15 cm in diameter, through some clasts are red jasper, petrified wood and sedimentary rock rip-ups from the underlying Moenkopi Formation.

The Agua Zarca Formation is thickest near San Ysidro and thins to zero north of Cuba (Woodward, 1987, fig. 11). It has a sharp disconformable contact on the underlying Moenkopi Formation characterized by stratigraphic relief, usually due to scour-and-fill, and erosional rip-ups. The Agua Zarca generally fines upward and appears to conformably grade upward to the Salitral Formation.

Salitral Formation

The Salitral Formation is mostly purple, blue and red smectitic mudstone with numerous calcareous concretions (Figs. 4C, 5). It forms slopes or strike valleys between the resistant Agua Zarca and Poleo Formations. Where the Poleo is very thin or absent, the Salitral can still be recognized by the characteristic purple and blue colors of its mudstones. Maximum thickness of the Salitral Formation is 102 m, but the unit is generally much thinner (<20 m).

Poleo Formation

Superficially, the Poleo Formation closely resembles the Agua Zarca Formation. Both units are sandstone- and conglomerate-dominated, resistant ridge and cuesta formers. However, mineralogy and clast composition allow ready distinction of the Poleo from the Agua Zarca. Poleo

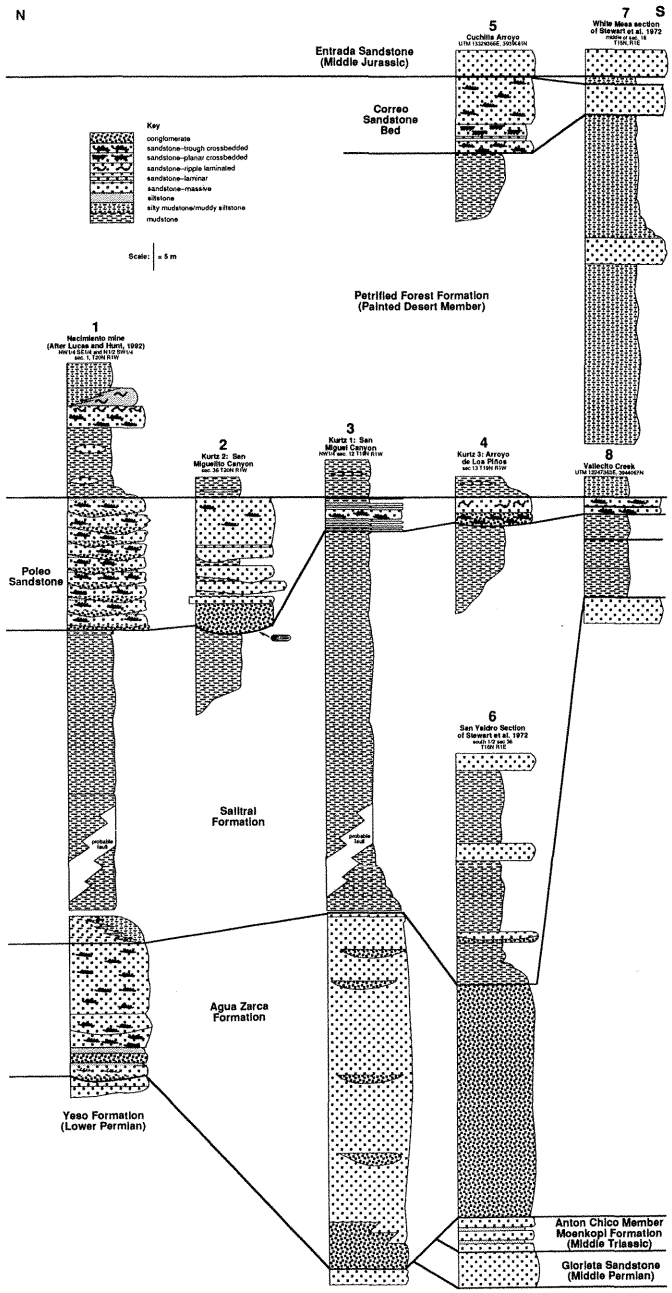

FIGURE 5. Measured stratigraphic sections of the Chinle Group in Sandoval County. See Figure 1 for location of sections.

sandstones are characteristically gray micaceous litharenites, in contrast to Agua Zarca quartzarenites. Poleo conglomerates are dominantly composed of calcrete clasts; siliceous clasts are uncommon, in contrast to the almost totally siliceous conglomerates of the Agua Zarca Formation.

The Poleo Formation in the study area (Fig. 5) has its maximum thickness of 40 m near Señorito Canyon (T20N, R1W). It thins dramatically southward to a wedge edge at San Miguel Canyon (T19N, R1W). Previous authors (Wood and Northrop, 1946; Stewart et al, 1972; Woodward, 1987; Lucas and Hunt, 1992) believed the Poleo pinches out southward at that point. However, thin (<10 m), lenticular remnants of the Poleo are present all the way around the southern flank of the Nacimiento and Jemez uplifts as far east as Vallecito Creek (T16N, R2E) near Jemez Pueblo (Fig. 5). Furthermore, below these Poleo lenses, and even where they are locally absent, the Salitral Formation can be recognized as a relatively thin (<20 m) interval dominated by purple and blue smectitic mudstones. South of San Miguel Canyon, for the purposes of geologic mapping, these thin units are best included in the Petrified Forest Formation (undivided), as earlier workers advocated (Woodward, 1987; Lucas and Hunt, 1992). However, from a stratigraphic point of view it is important to note that the Poleo and Salitral can be locally recognized throughout the outcrop belt south of San Miguel Canyon (Fig. 5).

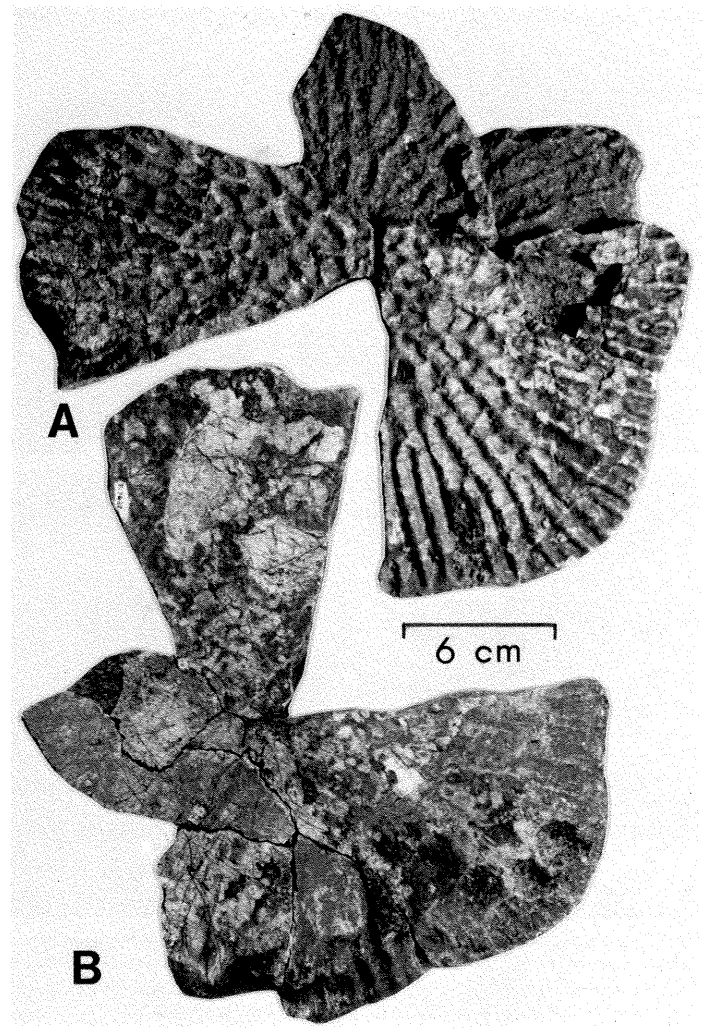

FIGURE 6. NMMNH P-17632, interclavicle of *Buettneria* sp. from NMMNH fossil locality 379, ventral (A) and dorsal (B) aspects.

The base of the Poleo Formation is a disconformity marked by stratigraphic relief, scour-and-fill and erosional rip-ups. Indeed, basal Poleo conglomerate clasts of calcrete closely resemble calcareous concretions that are abundant in underlying Salitral mudstones. This suggests extensive rip-up and reworking of Salitral concretions during Poleo deposition. The Poleo fines upward and appears to be conformably overlain by the Petrified Forest Formation.

Petrified Forest Formation

A thick (up to 340 m) stratigraphic unit dominated by reddish brown, smectitic mudstone overlies the Poleo Formation, and it is assigned to the Painted Desert Member of the Petrified Forest Formation (Lucas and Hunt, 1992). South of San Miguel Canyon, where the Poleo Formation is thin or absent, the entire mudrock-dominated Upper Triassic section above the Agua Zarca Formation is assigned to the Petrified Forest Formation (undivided). Although most of the Petrified Forest Formation is red-bed mudstones, it also contains numerous thin, often lenticular beds of trough crossbedded or laminated micaceous litharenite and calcrete-clast-dominated intraformational conglomerate.

The uppermost Petrified Forest Formation at most locations is 2 to 15 m of bench-forming litharenite and intraformational conglomerate of the Correo Sandstone Bed of the Painted Desert Member (Lucas et al., 1987, 1988; Lucas, 1991). Orange to reddish-brown, laminated, fine-grained

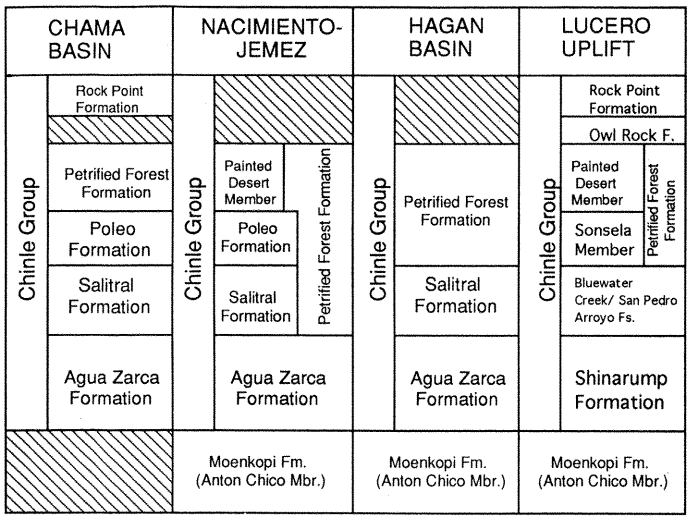

FIGURE 7. Correlation of Triassic strata exposed around the flanks of the Nacimiento and Jemez uplifts to Triassic strata in nearby areas.

sandstone and siltstone of the medial silty member of the Middle Jurassic Entrada Sandstone disconformably overlie the Correo Member.

PALEONTOLOGY

No systematic effort has been made to collect fossils from the Triassic outcrops around the Nacimiento and Jemez uplifts. No fossils have been observed in the Moenkopi Formation, and only petrified wood is known from the Agua Zarca and Poleo Formations.

Hunt and Lucas (1990, 1993; also see Hunt et al., 1988) described plant and vertebrate fossils from eight localities in the Petrified Forest Formation northwest of San Ysidro. These localities represent two fossiliferous intervals, one in the lower quarter of the Petrified Forest Formation (strata equivalent to the Salitral Formation to the north) and the other in the upper half of the formation. The lower horizon produced the plant *Zamites* sp., the lungfish *Arganodus dorotheae,* a large metoposaurid, a phytosaur, an aetosaur and coprolites. The upper interval produced unionid bivalves, a phytosaur, the aetosaur cf. *Typothorax coccinarum*, a dinosaur? and coprolites. As Hunt and Lucas (1990) concluded, the lower interval is probably of late Carnian (Adamanian) age, whereas the upper interval clearly is of Norian (Revueltian) age (also see Hunt and Lucas, 1993).

We report here the occurrence of an interclavicle of a large metoposaurid (Fig. 6) from NMMNH locality 379 (SW¼NE¼ sec. 11, T16N, R2E) in Salitral Formation mudstones along Vallecitos Creek northeast of Jemez Pueblo. This interclavicle corresponds well in size and pitting to the interclavicle of *Buettneria* (Colbert and Imbrie, 1956, fig. 10, pl. 27; Hunt, 1993, fig. 9b), to which it is assigned. Large metoposaurids are most characteristic of the late Carnian portion of the Chinle Group (Lucas, 1993; Hunt, 1993), so this fossil is consistent with a late Carnian age assignment for the Salitral Formation.

CORRELATION

Correlation of the Triassic section exposed along the flanks of the Nacimiento and Jemez uplifts with nearby Triassic outcrops is based on lithostratigraphy and paleontology (Fig. 7). This correlation is essentially the same as that advocated by previous workers, including Kurtz (1978), Woodward (1987) and Lucas (1991, 1993, 1995).

The Moenkopi Formation is not present in the Chama basin, north of the Jemez uplift, but the Agua Zarca, Salitral and Poleo Formations of the Chinle Group are, and can be directly correlated to these units in the study area. The Rock Point Formation in the Chama basin has no correlative along the flanks of the Nacimiento and Jemez uplifts. Evidently, more uppermost Triassic strata are missing beneath the sub-Entrada (J2) unconformity in the study area than in the Chama basin.

The Triassic section in the Hagan basin on the northern flank of the Sandia uplift is very similar to the section exposed at and around San Ysidro (Lucas, 1991; Lucas and Hecker, 1995). Direct correlation of members and formations can be made between the two areas (Fig. 7). The geophysical log of the Shell Santa Fe Pacific no. 1 well spudded near Bernalillo suggests continuity of the Triassic section between San Ysidro and the Hagan basin, underneath the Cenozoic basin fill of the Rio Grande rift (Lucas, 1991; Lucas and Hunt, 1993).

Correlation of the Triassic section exposed in the Lucero uplift (Lucas and Heckert, 1994) with the Triassic section along the flanks of the Nacimiento and Jemez uplifts is based on the following correlations: Shinarump=Agua Zarca, Bluewater Creek/Blue Mesa=Salitral, Sonsela=Poleo and Painted Desert=Petrified Forest above the Poleo. The detailed regional stratigraphic and paleontologic bases of this correlation have been presented by Lucas (1991, 1993, 1995).

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